APR 7 1897

Next Meeting, Wednesday, April 21st.

Entered as matter of the second class at the New York, N. Y. Post Office, November 26th, 1890.

VOLUME XIV.
NUMBER 2.

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FEBRUARY, 1897.

Annual Subscription $5.00
Single Copies . .50

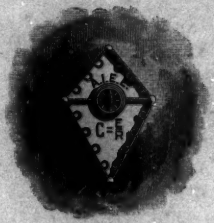
TRANSACTIONS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS.



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PUBLISHED BY THE INSTITUTE, UNDER THE SUPERVISION OF THE COMMITTEE ON PAPERS AND MEETINGS.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, February 17th, 1897.

The 113th meeting of the INSTITUTE was held this date at 12 West 31st Street, and was called to order by President Duncan at 8.20 P. M.

The Secretary read the following names of associate members elected and transferred at the meeting of the Executive Committee in the afternoon:

Name.	Address.	Endorsed by.
BROWN, ALBERT W.	Assistant Manager of Telephone Exchange, American Telephone and Telegraph Co., 39 Cortlandt St., residence, 27 W. 24th St., N. Y.	Harris J. Ryan. Fred'k Bedell. Ernest Merritt.
DINKEY, ALVA C.	Supt. Electric Dept., Homestead Steel Works, Munhall, Pa.	Edw. G. Waters. Ellicott Maccoun. H. A. Foster.
FRANKENFIELD, BUDD	Instructor in Electrical Engineering, The University of Wisconsin; residence, 640 State St., Madison, Wis.	D. C. Jackson. F. R. Jones. John E. Davies.
RIPLEY, WM. HOWE	Student, in Dept. of Electrical Engineering, Columbia University; residence, 605 Lexington Ave., N. Y. City.	Ralph W. Pope. F. B. Crocker. W. H. Freedman.
ROSA, EDWARD B.	Professor of Physics, Wesleyan University, Middletown, Conn.	H. A. Rowland. Louis Duncan. Hermann S. Haring
VAN DEVENTER, CHRISTOPHER	Student, Columbia University; residence, 626 Lexington Ave., N. Y. City.	F. B. Crocker. W. H. Freedman. Geo. F. Sever.
WOODWORTH, GEO. K.	Electrician, Crawford Mfg. Co., Hagerstown, Md.	Harris J. Ryan. Edw. L. Nichols. Fred'k Bedell.

Total 7.

TRANSFERRED FROM ASSOCIATE TO FULL MEMBERSHIP.

Approved by Board of Examiners, Dec. 29th, 1896.

DAWSON, PHILIP.	Associate and Chief Engineer with R. W. Blackwell, 39 Victoria St., Westminster, London, England.
GIBBS, LUCIUS T.	Manager and Chief Engineer, Gibbs Electric Co., Milwaukee, Wis.
SPRAGUE, FRANK J.	Vice-President, Sprague Electric Elevator Co., 253 Broadway, N. Y.
LESLIE, EDWARD ANDREW	Vice-President and Manager, Manhattan Electric Light Co., Ltd., New York City.

Total 4.

THE PRESIDENT:—The paper this evening, gentlemen, will be by Mr. Howell, entitled "The Conductivity of Incandescent Carbon Filaments, and of the Space Surrounding Them."

Mr. Howell read the following paper:

A paper presented at the 113th Meeting of the American Institute of Electrical Engineers, New York, February 17th, President Duncan in the Chair, and Chicago, February 24th, 1897

CONDUCTIVITY OF INCANDESCENT CARBON FILAMENTS, AND OF THE SPACE SURROUNDING THEM.

BY JOHN W. HOWELL.

The first part of this paper, which relates to the conductivity of carbon filaments, is in the nature of a discussion of a paper read before the INSTITUTE by Prof. Anthony, at the May meeting in 1887.

Prof. Anthony spoke of a change from negative to positive of the temperature coefficient of some carbon filaments which he

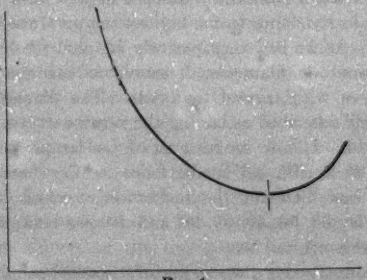

FIG. 1.

had observed. He illustrated the change by a figure, which I will reproduce here for reference. (Fig. 1.)

Prof. Anthony stated that this change did not occur in all filaments, and that he was unable to explain the circumstances under which it did occur.

Prof. Elihu Thomson, in his discussion of Prof. Anthony's

paper, said that he had observed the same phenomenon, but had not investigated it sufficiently to explain its cause.

About four years ago an inventor offered to the General Electric Company a method of coating carbon filaments with metal, claiming thereby a very great improvement in the performance of the filaments. The metallic coating was applied by heating the filament to high incandescence in the presence of the vapor, which was obtained from a very thick dark colored liquid, the application being made by the same means as is employed in the ordinary hydrocarbon flashing process. The proof which he gave that his filaments had a metallic coating was the fact that the resistance of these filaments was lower at about red heat than it was at higher temperatures.

In order to test his assertions, I treated a number of filaments with his dark liquid, and, for a comparison, treated in exactly a similar manner a number of similar filaments, using ordinary gasolene. To the surprise of both of us, the gasolene filaments showed the same rise in resistance, after passing the dull red temperature, as was shown by the filaments supposed to have a metal coating. This fact led me to investigate this phenomenon.

I had previously made resistance curves of a great many Edison lamps, which had filaments made without hydrocarbon flashing, and I knew that the filaments of all these lamps continued to fall in resistance to the highest temperature which they would stand. As we had very recently adopted the hydrocarbon treatment upon our filaments, I associated the change in the resistance curve with treated filaments. The filaments which I have previously described as having the reverse curve, were quite heavily treated. I now made a set of ten lamps with various amounts of treatment, all made from similar base filaments. These lamps had filaments the resistances of which, when cold, were 90, 80, 70, 60, 50, 40, 30, 20 and 10 per cent. of the cold resistance of the original base.

I found upon plotting the curves of these filaments, that the untreated filament fell in resistance as it was made hotter, and that this fall continued to the highest temperature at which I dared run it.

The slightly treated filament fell in resistance more rapidly than the untreated filament at first, and less rapidly as the high temperatures were reached, its curve finally rising above that of the untreated filament. As the amount of treatment is increased,

the curve falls more and more rapidly at first, and less rapidly at the higher temperatures. When we reach the filament treated to 50 per cent., we find that it falls rapidly to about 50 per cent. of its cold resistance, and remains practically constant at higher temperatures. The curves of filaments treated to less than 50 per cent. all rise after reaching their lowest point, which is reached at about 50 per cent. of their three watts per candle voltage.

These curves show the changes in resistance of these filaments. The ordinates are percentages of the cold resistances of the various filaments, so that all curves start from the 100 per cent. mark. The abscissæ are percentages of the voltages at which the various lamps take three watts per candle. The bottom curve on this sheet illustrates the resistance curve of a carbon filament which had been treated to about one per cent. of its original resistance. This made a filament which was nearly all treatment. This curve shows an increase in resistance from its lowest point to the last point obtained, of about 25 per cent.

This lamp was measured at the Edison Laboratory by Mr. Kennelly and myself. The readings were very carefully taken upon very sensitive instruments, and there can be no doubt as to the accuracy of the curve, as it agreed very well with the measurements I had previously made upon the same filaments. These curves can be obtained a good many times from the same filaments, so there is no permanent change in the filaments which in any way accounts for the rise in resistance. The cold resistances of the filaments, after being measured, were found to be the same as before any measurements were made.

These same ten carbons were taken from the lamps and put into a baking oven, the temperature of which could be regulated very nicely by an electric heater. These filaments were heated to about 500 degrees Fahr., the temperature being measured by two mercury thermometers. The resistance curves obtained in this way are shown on the upper part of the sheet, and agree quite well in character with the resistance curves obtained by measuring the volts and amperes of the lamps, so there is no doubt that the changes in resistance are due to temperature, and to nothing else.

I then obtained untreated base filaments from as many kinds of amorphous carbon as I could obtain, and plotted their resistance curves.

I tried filaments made of bamboo, silk, cotton, cellulose (made

by the ordinary squirt process), tamadine, and paper. All of these base carbons gave the same curve, and all of them continued to fall in resistance as long as I was able safely to increase the temperature.

These carbons were quite different in their physical characteristics. The silk filaments were the most porous, and had the roughest and the best heat radiating surface, while the tamadine filaments were very dense and had a very highly lustrous surface.

I was entirely unable for a long time, after making these curves, to come to a satisfactory theory regarding them. The reverse curve is not caused by changes in the characters of the

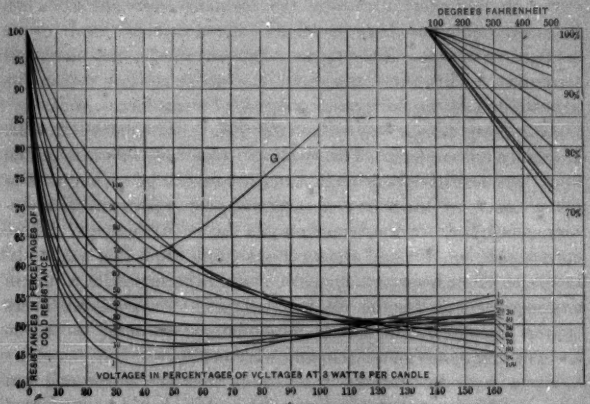
DEGREES FAHRENHEIT
100 200 300 400 500
100%
90%
80%
70%
RESISTANCES IN PERCENTAGES OF COLD RESISTANCE
VOLTAGES IN PERCENTAGES OF VOLTAGES AT 3 WATTS PER CANDLE
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160

FIG. 2.—Curves showing changes of Resistances of Lamp Filaments with Voltage and Temperature.

surfaces of the carbons, due to emissivity, because no corresponding changes in emissivity occur.

I made observations upon untreated and heavily treated filaments, to see if they acted differently in regard to their expansion with heat, thinking that possibly the changes in the resistance curve may have been caused by a change in the expansion curve with temperature. These observations were not very refined, being simply observations made by means of a telescope, but they showed clearly that all of the carbons expanded with heat, and apparently there was no difference in this respect.

It has been the custom for some time to speak of the carbon which is obtained by the treating process as graphite carbon, and knowing that Mr. Edison had, in 1881, made some filaments of graphite, by pressing the pure graphite under very great pressure into the form of loops, I was very anxious to obtain a lamp containing one of these filaments, to see whether it would have the same resistance curve as the other forms of untreated carbon. I have very recently obtained one of these lamps from Prof. Barker, of the University of Pennsylvania, and upon plotting its resistance curve I was very much pleased to find that it had the same characteristics as the heavily treated filament. It reached its minimum resistance at a dull red heat, and from this point, as the temperature was increased, the resistance increased also. This

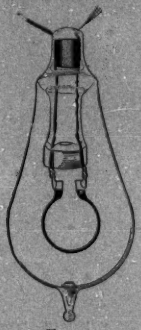

FIG. 3.

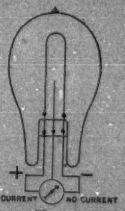

FIG 4.

curve is marked o upon the sheet on which the other curves are plotted.

It will be observed that the resistance curve of this filament does not fall as much as the other curves, and rises much more. This may be due to the different natures of the two kinds of graphite, or to structural differences. The top of the loop of the graphite filament got much hotter than the rest of it; this would cause this part to start rising before the rest had ceased falling in resistance, and this may account to some extent for the less total fall in resistance of this filament. The resistance of this filament, after the measurements had been made, was just the same as before they were made. This indicates quite clearly that our calling the treated carbon "graphitic" is correct, and that the

change in the resistance curve of treated filaments is due to the graphitic nature of the layer of carbon which is put on during the treating process.

The graphite filament lamp referred to is shown in Fig. 8.

The second part of this paper, which relates to the conductivity of the vacuous space surrounding incandescent filaments, may be considered as a discussion of the paper upon the "Edison Effect" in incandescent lamps, which was read before the INSTITUTE by Professor Houston, in October, 1884, and which was the first paper read before this society.

"Edison Effect" is the name given to the effect produced by those currents, first observed by Mr. Edison, which pass from one leg of an incandescent filament across the vacuous space to the other leg, and which can be observed by connecting a galvanometer between the positive lamp terminal and a wire sealed into the bulb and projecting into the vacuous space.

Figure 4, which is taken from Professor Houston's paper, serves to illustrate Mr. Edison's original experiment. The galvanometer indicates a current flowing from the positive lamp terminal through the galvanometer and third lamp wire, and through the vacuous space to the negative leg of the incandescent filament. If the external connection of the galvanometer be changed from the positive terminal to the negative terminal, no current will flow through the galvanometer. This effect can be observed in the most highly exhausted lamps. A lamp so highly exhausted that it shows no glow when tested with an induction coil, giving a spark $\frac{1}{4}''$ long, will allow a current sufficiently large to show plainly on a not very sensitive galvanometer, to pass through its vacuous space. This current increases as the temperature of the filament is increased, but in a well exhausted lamp is never greater than a very few milliamperes, when the lamp is burned at about $2\frac{1}{2}$ watts per candle.

In 1884 Mr. Preece secured from Mr. Edison some lamps having wires sealed into the bulbs, and read a paper before the Royal Society describing some experiments made upon them, illustrating the "Edison Effect."

Professor Fleming read a most elaborate paper before the Physical Society of London, in March, 1896, upon this same subject. Professor Fleming's experiments proved that in well exhausted lamps the vacuum is not a conductor in the ordinary sense of the word, and that the current which passes through it is carried by

negatively charged molecules, which pass constantly from the negative leg of the incandescent filament to the positive leg and to any inserted wire, thus bringing the inserted wire to the same potential as the negative leg. Professor Fleming also proved that these molecules pass in straight lines, and that their passage is completely or almost completely stopped by a glass or mica screen placed between the negative leg and the inserted wire. The following experiments serve to illustrate these effects:

Figure 5 shows a lamp having a glass tube surrounding one leg of the filament, and a wire sealed in the side of the bulb, which projects into the centre of the vacuous space. When the leg of the filament which is in the glass tube is made positive, and the filament heated to about a 2½ watts-per-candle temperature, the galvanometer, which is connected between the wire and the positive lamp terminal, shows a strong deflection, but when the leg in the tube is made negative the galvanometer, being as

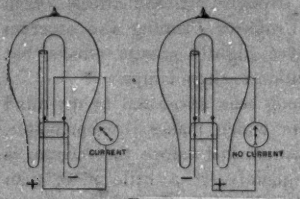

FIG. 5.

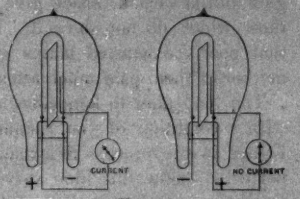

FIG. 6.

before connected between the wire and the positive lamp terminal, shows no deflection.

Figure 6 shows a lamp having a platinum plate 2¼″ long and ¼″ wide between the legs of the filaments, and a wire inserted in the vacuous space. I also used lamps having a similar plate made of glass, similarly placed. In both of these lamps, when the vacuum was high, no current was produced between the wire and the positive terminal when the wire was shielded from the negative leg; but shielding the wire from the positive leg made no hindrance to the passage of the current. The facts that no current flows when the galvanometer is connected between the negative terminal of the lamp and the inserted wire, and that a shield between the positive leg and the inserted wire has no effect upon the current, show that positively charged molecules are not emitted by the positive leg; while the screen effects just de-

scribed show that the negatively charged molecules pass in straight lines.

The facts, then, are these: The galvanometer indicates a current flowing, as we designate the direction of currents, from the wire to the negative leg; while experiments prove that the charged molecules which carry the current actually pass from the negative leg to the wire. These facts are entirely in accord with the results obtained by Crookes and others in their investigations of currents in high vacua.

If an alternating current is used to render the filament incandescent, the galvanometer will indicate a current with the connection made to either lamp terminal, because both are equally positive. The current thus produced is a uni-directional one in the galvanometer, and illustrates very well the uni-lateral conductivity between the incandescent filament and the wire.

Mr. Preece states in his paper that lamps which show a blue glow in the vacuous space give stronger "Edison Effects" than those which do not show it. Professor Fleming also observes that poorly exhausted lamps give slightly greater effects, but neither of them paid much attention to these lamps.

The blue glow in lamps has long been associated in my mind with a condition of the vacuum which makes it a conductor. Lamps in the process of exhaustion, just before the vacuum is perfected, show this blue very plainly, if a little more than normal current is sent through the filament. The blue increases as the current is increased and becomes very dense at very high temperatures. This blue indicates a current passing from one leg of the filament across the vacuous space to the other leg.

I observed several years ago, that at a high temperature .04 or .05 of an ampere more current flowed through a lamp showing a good blue than through the same lamp, at the same voltage, when the blue had disappeared. I concluded that this extra current flowed through the vacuous space between the legs of the filament.

If a direct current about 20 or 30 per cent. greater than the normal current be passed through a lamp filament when the vacuous space shows a blue glow, the positive joint between the filament and the platinum wire gets red hot, while the negative joint remains cool.

I have always considered this as proof that the resistance to the passage of a current through a vacuous space was chiefly at

the surface of the positive electrode, as the energy was chiefly developed there. If an alternating current is used, both joints get equally hot.

If a lamp be burned at normal incandescence with a direct current, when the vacuous space shows a good deal of this blue, the negative leg of the filament becomes coated with a carbon soot. This effect can be obtained in a few minutes if the blue is dense and the filament is run above a normal incandescence. This I have considered to be due to an electrolysis of a hydrocarbon gas in the lamp.

The lamps which show only a slight amount of this blue glow, if burned at normal incandescence, will not show this carbon soot perceptibly, and the blue will entirely disappear if the lamp is burned for a few hours. This blue is caused more by the charac-

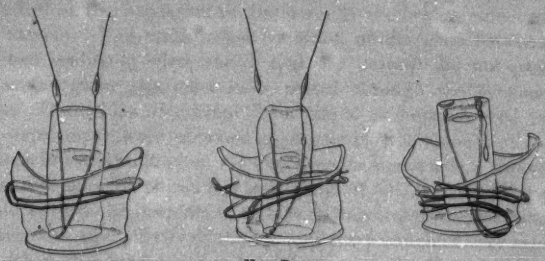

FIG. 7.

ter of the residual gas than by the degree of exhaustion. Lamps having a residual of bromine vapor do not show it at all, neither do they show any "Edison Effect." I have seen ordinary lamps ready to be sealed off the pumps which showed blue and then no blue, and blue again, at regular intervals of a few seconds. Such lamps show corresponding changes in the "Edison Effect."

If the current be gradually increased in a lamp which shows good blue, the positive joint will get hotter and hotter and finally its platinum wire will fuse. At this stage the resistance to the flow of current across the vacuous space is not great, and if the conditions are such that at this time all the resistance in circuit with the lamp has been cut out, so that the current flowing will be practically determined by the resistance of the lamp and the leads, enough current will flow through the vacuous space to

fuse the platinum wires, which are sealed in the glass. This fusion is not due to the same cause as the fusion of the positive joint wire by the vacuum current, because it fuses both positive and negative wires, while the vacuum current fuses only the positive. This fusion of both wires is due to the fact that the low resistance of the vacuous space allows more current to pass than the platinum wire can carry. This is further demonstrated by the fact that a 10-ampere fuse in the circuit will often blow when this happens.

In order to measure the currents which pass from one leg of the filament to the other across the vacuous space, I measured the current at a given voltage of a number of lamps; first when

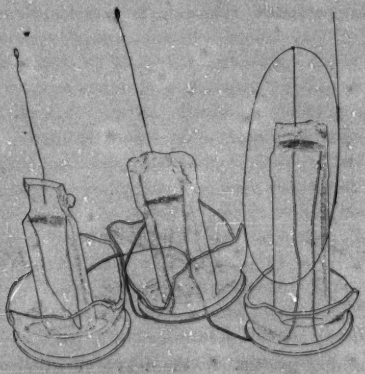

FIG. 8.

the lamps showed a good dense blue, before they were well exhausted, and again after the same lamps were well exhausted and showed no blue. Some 55-volt 24 c. p. lamps showed .4 of an ampere more on the first reading than on the second. All of this .4 of an ampere must have passed through the vacuous space, for the resistance of the filament remained practically unchanged or became a little lower during the operation.

I also measured the currents which passed across the vacuous space, when these currents were large enough to fuse the joint wire, and also when they were large enough to fuse both platinum leading-in wires. I found that from one to five amperes

passed across the vacuous space when the positive joint wire only was fused, and that when both wires leading through the glass were expanded so by the heat of the current that the glass was shattered, the current measured from 10 amperes to more than 25 amperes.

In order to measure the instantaneous current which shattered the glass, I raised the hand of the ammeter to successively higher points, to find the mark at which the current would just raise the pointer. I used an ammeter measuring 25 amperes, and when the pointer was raised to the 25 ampere mark the current through the vacuous space caused it to jump beyond this mark.

Figures 7 and 8 show stems of lamps exhibiting the effects of currents of from one to 25 amperes passing through the wires and the vacuous space. The glass about the wires shows the fusing effect of the current, and the fracture of the glass shows the effect of the expansion of the wires by the heating effect of the current. The undisturbed condition of the glass between the two leading-in wires shows that the current did not pass across the glass, but must have passed through the vacuous space. Gradations of current from one to 25 amperes, used in this experiment, were obtained by regulating the amount of resistance in the circuit when the experiments were made. Unless some resistance had been left in the circuit, all of these lamps would have shown currents as high as 25 amperes or thereabouts, because the conductivity of the vacuous space increases very rapidly when the effect is great enough to start the fusion of the wires.

The lamp shown in Figure 9 illustrates the fact that the heat produced at the positive joints by the "Edison Effect" current is not simply the result of a mechanical bombardment. This lamp was exhausted to show a good blue. The temperature of the filament was raised sufficiently to cause vacuum currents large enough to heat the positive joint red hot. The outer end of the middle wire was then connected to the positive lamp terminal. When this was done the positive joint became cool and the middle wire got red hot. This was repeated several times. The middle wire got hot enough to fuse the end, which was platinum. This indicates that most of the heat is caused by the charged molecules coming in contact with some conductor which will carry away their charge. The current was not measured in this experiment.

Figure 10 shows the lamp used in a similar experiment. The middle wire carried a copper plate about 1″ long and ¼″ wide. This lamp was exhausted to show a good blue. An ammeter was connected between the middle wire and the positive lamp terminal. As the current was gradually raised, the vacuum current heated the copper plate until it was fused, as shown in the figure. The ammeter in this case indicated over five amperes flowing through the vacuous space between the negative leg of the filament and the copper plate.

I next tried a series of experiments to determine whether the current which passes through the vacuous space when the blue glow is present was the effect of charged molecules moving in straight lines only, from the negative leg, or whether this current would pass around a screen. If a blue glow should appear in lamps with a shield between the legs of the incandescent filament, it would be an indication that the charged molecules under

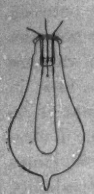

FIG. 9.

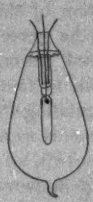

FIG. 10.

FIG. 11.

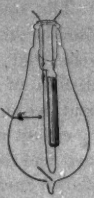

FIG. 12.

FIG. 13.

these conditions could carry a current between the two legs in other than straight lines, and if the positive joint should get red hot in such a lamp it would indicate that the charged molecules pass around an obstacle quite freely. For this experiment I used a lamp with a glass plate 2¼″ long and ⅛″ wide between the legs of the incandescent filament. It was necessary to raise the filament in this lamp to a very high temperature before the blue appeared, and then instead of appearing gradually, as it does in ordinary lamps, it appeared suddenly and in great abundance and the positive joint got red hot, so that it was necessary to reduce the temperature of the filament to prevent the fusion of the joint wire. As the temperature was reduced, the blue gradually decreased, as it does in ordinary lamps.

When the temperature was so reduced that very little blue was visible, the blue would increase gradually again if the tem-

perature was increased. When the circuit was broken, the filament had to be again raised to the high temperature before the blue again appeared. In this lamp the blue appeared at 136 volts, and remained when the pressure was reduced to 109 volts, but would disappear between 109 and 101 volts.

My next experiment was with a lamp (shown in Fig. 11) having a platinum screen between the legs of the filament and a platinum wire sealed in the side of the bulb and projecting in the vacuous space, with its end bent so as to run parallel with one leg of the filament for about 1″ between the filament and the platinum plate. When this filament was heated to about a 2½-watts-per-candle temperature, the vacuum current did not pass around the screen and no blue showed in the vacuous space. That leg of the filament being negative which was on the same side of the screen as the wire which was sealed into the bulb, I connected the galvanometer between this wire and the positive lamp terminal. The galvanometer showed a strong current. On breaking the galvanometer circuit, blue appeared on the positive joint and in the bulb. I repeated this several times. It occurred when the temperature was considerably below the temperature necessary to start the blue around the screen.

In each case, connecting the galvanometer between the wire and the positive terminal would cause blue to appear about the inserted wire and the negative leg, and breaking the galvanometer circuit would cause blue to appear on the positive joint, and in the vacuous space about the positive joint, and about the negative leg of the filament.

With this same lamp I observed that when the filament was at a temperature not sufficient to start the blue, if I touched the positive terminal with one finger, and the inserted wire with the other, the blue immediately appeared in the vacuous space about the positive joint and the negative leg of the filament.

These experiments demonstrate that in lamps exhausted so as to show a good blue, the charged molecules have some difficulty in starting their passage from one leg to another around an obstacle, but maintain their passage after it has been once established. Also, that their passage around an obstacle is easily established by starting a flow of charged molecules from the negative leg through a small unobstructed part of the vacuous space, to an inserted wire which is connected to the positive terminal, and then breaking the positive terminal connection.

To determine how large a current could be made to flow around an obstruction in lamps exhausted to show a good blue, I used a lamp shown in Fig. 12, having a glass tube about the negative leg, and the wire sealed in the side of the bulb, running parallel with the positive leg for about 1″. I connected an ammeter between the inserted wire and the positive lamp terminal, and raised the temperature of the filament until a dense blue appeared in the vacuous space, and about the wire and the end of the glass tube. The temperature of the filament was raised until the vacuum current fused the platinum wire which was sealed into the bulb. When this occured, the ammeter indicated 2¼ amperes, and remained at this reading one or two seconds.

Any of the lamps in which the condition of the vacuum is just right, showing the blue glow, will show a current in a galvanometer connected between the wire inserted in the vacuous space, and the *negative* lamp terminal, but in all cases this current is small. One-half milliampere is the largest current I have observed under these conditions.

I next tried some experiments with lamps like the one shown in Fig. 13, which has two wires sealed in opposite sides of the bulb, which project inward to a point near the filament about ¼″ above the joints. This lamp was exhausted to show a good blue. The galvanometer was connected between the wires which were sealed in opposite points of the bulb. No current was indicated until the temperature of the filament was raised quite high, and the blue glow was quite intense.

Under these conditions the galvanometer indicated a current of .1 milliampere

I have made experiments upon two lamps containing bromine vapor. One of these lamps which contained bromine enough to depress the barometric column $\frac{1}{10}$″, showed no "Edison Effect" when the potential was run up as high as 170 volts, using a 110-volt lamp.

The second lamp had very much less bromine vapor in it, and showed a very slight "Edison Effect." This lamp acted very peculiarly. When first tried it gave an "Edison Effect" which changed very little in value between 105 and 146 volts. At 120 volts, the vacuum current showed a deflection of the galvanometer of 14 scale divisions, while at 128 volts it showed a deflection of only 12 scale divisions. I observed this several times. This was quite a large reverse change, as the current at 146 volts only in-

creased enough to give a deflection of the galvanometer of 16 scale divisions. This change was observed on several days, but it was less marked each time it was tried, until it finally disappeared.

The question naturally arises, what causes the blue glow in the vacuous space? The glow is luminous, and luminosity can only come from matter; consequently we conclude that the vacuous space, when blue shows, is filled with luminous molecules, and as these molecules are not of themselves luminous, we must seek for the cause of their luminosity.

We have seen that the negatively charged molecules liberate considerable energy on coming in contact with a body that conveys away their charge. We have also seen that when the blue glow is present there is a considerable flow of charged molecules through the vacuous space, and that the naturally rectilineal movements of these molecules are disturbed.

We also know that molecules are emitted from the positive leg about as plentifully as from the negative leg, although these molecules do not carry a positive charge.

The conclusion seems to be that the blue glow is a manifestation of the energy developed by the meeting of the charged molecules with other molecules which take away part or all of their charge.

Well exhausted incandescent lamps which have burned a long time show a black deposit on the inner surface of the bulb. In lamps with thick, stiff, single-loop filaments, in which the two legs lie in the same plane, a light line may be observed in the black deposit, which is caused by the shielding of this line by one leg, from the molecules emitted by the other leg. This line shows with about equal clearness opposite both legs, indicating that carbon molecules are constantly emitted from both legs, equally and in straight lines.

In lamps which have been imperfectly exhausted, the black deposit sometimes appears in patches, symmetrically placed with reference to the carbon. I regard these figured discolorations as indications of disturbances in the rectilineal paths of the molecules, and of the influence of the magnetic field upon the disturbed molecules.

The activity of the molecules carrying current across the vacuous space seems to depend more on the temperature of the filament than on the potential difference between the legs, 40-volt lamps

showing about as strong effects as 140-volt lamps. The energy they exhibit in one direction seems to be very much greater than we would expect from molecules actuated by a potential difference of only 40 or 50 volts. The action of these molecules in carrying electricity in one direction only, may be an indication of the nature of the action between molecules in solid conductors carrying currents, rather than an illustration of the action of statically charged molecules.

Discussion.

Mr. John W. Howell:—After I had written this paper, I broke the lamp having the graphite filament and took the filament out - a part of it—and measured its specific resistance. Its specific resistance (the resistance of a piece one inch long and one circular mil area) was 450 ohms. The lowest specific resistance I have ever measured of amorphous carbon is about 2200 ohms. The treatment obtained by hydrocarbon deposit is about 350 ohms, which is about six or seven times as low; and this graphite lamp was 450 ohms, which was very nearly the figure of the carbon obtained by treatment, and I think if it had been a more solid graphite it would have been lower. I can also say that the specific gravity of graphite is practically the same as the specific gravity of the carbon obtained by hydrocarbon deposit.

The President:—How was that filament made?

Mr. Howell:—It was simply made by making a die, filling it with graphite and solidifying it under great pressure—so great pressure that it made a solid graphite filament of it.

Dr. A. E. Kennelly:—I believe that I voice the general sentiment in saying that this is a very interesting paper, both by reason of what it contains of investigation and by reason of what it suggests for further inquiry.

I remember having taken part in the measurements of resistance in the lamp filament referred to. I believe that the theory given in this paper was suggested at that time for the apparently abnormal behavior of its resistances, but the additional evidence was not then forthcoming which enables Mr. Howell to make so strong a case for that theory in this paper.

It is perhaps no more surprising that graphite should differ markedly from ordinary carbon in its temperature co-efficient of resistivity, than that diamond should differ markedly from ordinary carbon in its hardness.

Incidentally it is curious to observe from the curves in the paper that approximately five per cent. of the voltage needed to produce an inefficiency of three watts per candle, raised the temperature of the filaments experimented on to 500° F., or 260° C.

It has long been known that the passage of a continuous current through a Geissler tube set up a series of pulsatory currents

or discharges, which are capable of producing alternating currents in a separate circuit, through the intermediary of an alternating current transformer. So far as I know, however, it has been pointed out for the first time in this paper, that an alternating current passed through an incandescent lamp giving the "Edison Effect" is capable of producing in a branch circuit through a third wire in a lamp, continuous or at least undirectional currents. Consequently it is interesting to observe that a vacuum tube, in the broadest sense of the term, is capable of supplying not only alternating currents from continuous currents, but also continuous currents from alternating currents.

As regards the results obtained in the interesting manner described, it would appear that some of these observations differ from those quoted as obtained by Dr. Fleming. It would seem that Dr. Fleming took the position that the blue discharge can only travel in straight lines, whereas in some of the experiments here referred to, as, for example, those in connection with Figs. 11 and 12, the blue discharge and the "Edison Effect" did apparently go around a corner, and a sharp corner too.

I am unable to follow the conclusion mentioned by Mr. Howell, that the change in the development of heat from the positive joint to the middle wire, when the connections are changed, indicates that no bombardment can take place. It seems to me possible that bombardment might still take place under a directive influence determined by the point of connection. No doubt Mr. Howell can make this matter clear.

MR. E. A. COLBY:—I am deeply interested in Mr. Howell's paper, especially the latter part of it, referring to the so called "Edison Effect." While I am not prepared to-night to present any theory as to the phenomena observed, I can say that the characteristics which Mr. Howell has mentioned are well known to me. I would like to ask if he has substituted for the galvanometer which he used in measuring the currents, the still more sensitive instrument, the telephone, and whether he has attempted with its aid to explore the vacuous space by the insertion of platinum wires at different points in the glass bulb. Some years ago I tried an experiment of this character which was described in a discussion before the INSTITUTE. I sealed into a lamp bulb in the plane of the filament a number of platinum wires about one inch apart. Connecting the terminals of the telephone with the positive leg of the lamp, and with one of these wires I observed a note in the telephone which varied in pitch according to the position of the wire sealed into the bulb. When the telephone was connected to the positive leg on one side, and to the platinum terminal which was nearly at the middle of the filament, or more correctly on the diagonal to positive terminal of the area enclosed by the legs of the filament, I obtained the maximum note, and as I carried this terminal of the telephone near to the negative leg of the filament I got practically no sound whatever. I also inserted in a similar

lamp a glass plate, upon which I obtained a deposit of carbon upon one side only, the depth of the deposit apparently increasing from the base of the lamp to the apex, indicating that particles of carbon were actually transferred from one leg of the filament to this glass plate. I then attempted to produce mechanical motion within the bulb of the lamp by constructing a very delicate mill out of mica vanes, and supporting the same between the legs of the filament. This mill was composed of four aluminium arms with mica vanes attached, and was shaded—half of it—so that only one portion would be exposed to the impact of the carbon molecules. This experiment was only tried once and proved a failure.

I notice that Mr. Howell reaches the conclusion that the luminosity is due to the energy set free by the impact of the molecules of matter present, which is undoubtedly the case. I should be very glad if he would express an opinion as to what may be the nature of these molecules, whether they are particles of carbon, or whether they are hydrogen gas, or compounds of hydrogen with carbon.

There is one other point which I would like to bring up, and that is the effect of gases, such as bromine, left in the bulb. I entirely agree with Mr. Howell that when bromine gas in an appreciable amount is left in a bulb, the blue discharge disappears, and that the current across the vacuous space is absent. I have also found the same to be true if the vacuous space or the space within the lamp bulb is occupied by the vapor of chloroform and various other hydrocarbons. But I have also noticed that when certain compounds are present in the bulb, the blue discharge, instead of disappearing, actually increases. And notably I recall a case where a lamp had been exhausted which had attached to the bulb a tube containing mercuric cyanide. Upon heating this tube until the glass was ready to collapse we forced the vapor of mercuric cyanide, or possibly the components of mercuric cyanide, into the lamp bulb. Upon raising the current appreciably afterwards, the blue discharge suddenly appeared and spread out in concentric rings from the positive leg nearly reaching to the negative, and a short circuit resulted after the lamp had remained on the pump a few moments. The same increase in the blue discharge I had also observed in lamps containing filaments which were imperfectly carbonized. In the earlier manufacture of the tamadine filament we undertook to carbonize the material, utilizing the same temperature with which we had been carbonizing the ordinary paper and silk filaments, but unfortunately we were unable to reach a temperature high enough to effect complete decomposition of the tamadine. Filaments made in this way, upon being sealed in the lamp bulbs and having a current passed through them, became further carbonized, and the result was, that a large amount of gas was liberated and the globes were filled completely with a violet blue discharge, and if the

current was allowed to continue, short circuits inevitably resulted. This indicated to me at the time, that the blue discharge was possibly due to the presence of gases which were liberated from the carbon filaments, and that the blue discharge in other lamps which appears when a high degree of exhaustion is reached, appearing as it does at the stubs or the points at the lowest temperature, possibly was due to the presence of occluded gases at those points, which in working their way out gave rise to the blue discharge. To investigate this matter further, I remember that we sealed glass tubes to the platinum wires so that the tubes surrounded the stubs. Upon raising the current to the point at which the blue discharge usually appeared we failed to obtain it. But upon raising it still more, suddenly the blue discharge shot out from the glass tube surrounding the positive leg in a large amount, and the temperature at that point was so high that the glass tube was fused. I have noticed also the same effect which Mr. Howell mentions of the heating of the platinum wire on the positive side due to the vacuum current. I have succeeded more than once in obtaining this effect without fusing the platinum wire; raising the wire to a red heat throughout its seal from the interior to the outside, and upon reversing the current obtaining the same effect upon the opposite side. The blue discharge first appearing at the stub and gradually traveling down the wire, I thought at the time that it might be due to gases occluded in the platinum wire itself. You are all familiar with the fact that there is a process of electric forging in which the metal is connected to the negative pole and inserted into a liquid bath, and upon turning on a sufficient amount of current the negative electrode becomes heated to a very high temperature. I believe the theory for this is that the metal becomes enclosed in an atmosphere of hydrogen, the resistance of contact being so high that the temperature is raised to a white heat. It occurred to me that platinum, occluding as it does so much hydrogen, and possibly, also the stubs and filaments, which at very high temperatures may be giving off hydrogen as a result of further decomposition, might account for the appearance of this blue discharge. I am exceedingly grateful, personally, to Mr. Howell for his lucid explanation of the phenomena.

DR. SAMUEL SHELDON:—Last year, when Röntgen first gave out his results, I was looking through the literature of the subject of Crookes tubes, and I came across one piece of information which struck me as rather peculiar and which may bear upon this subject here. It was that a Crookes tube with two electrodes constituted a condenser; that the capacity of this condenser depended upon the condition of the exhaustion, upon the size of the electrodes and upon the distance between the electrodes; that the dielectric of this condenser, if it can be so called, exhibited the peculiar property of breaking down when the voltage impressed upon the electrodes exceeded a certain amount,

and that when a Crookes tube was properly operated so as to glow, that the voltage upon the terminals was always of a definite amount; it never exceeded that amount, for if an electromotive force which was greater than the amount necessary to produce this glow discharge should be impressed upon the two electrodes, the difference of potential was reduced by an adjustment between the internal resistance of the coil or source of electromotive force and a series of pulsatory discharges of widely varying frequency between the two electrodes. I speak of this in this connection because it seems to me perhaps to explain the experiment of Mr. Howell represented in Figure 11, where the discharge was not observed between the negative terminal and the positive terminal when a shield was interposed, but which was started at the moment that the intermediate wire was connected with the negative terminal. In the latter case, the length of path between the interposed wire and the positive terminal was lessened to such an extent that perhaps, possibly, the voltage which was impressed on the two terminals and which was in this case limited, because it was short-circuited through the filament, was enabled to give a discharge, and that once having been started the character of the discharge was maintained, as is often the case in a Crookes tube.

Mr. Colby:—I would like to ask Mr. Howell if he has made any examination of the blue discharge by means of the spectroscope. I have in my notes, under October 11th, 1883, an instance where we had this pronounced blue discharge. Upon examination of the discharge with the spectroscope, a number of very bright lines to the right of the D or sodium line were seen. But unfortunately, before their position could be fixed the lamp short-circuited. In every case I find my notes indicate the presence of the same lines. I have here a small diagram of the spectrum, indicating as nearly as could be done by three observers, Mr. Weston, Professor Garver and myself, where these lines were located. The sodium line was clearly visible. The most marked line was a bright green, which Mr. Weston thought was possibly due to the presence of mercury. It might possibly have been mistaken for hydrogen. Hydrogen and oxygen would undoubtedly be present from the decomposition taking place. Mr. Weston's theory is—I am reading notes which were made at that date—that the presence of hydrogen brings out the mercury lines. The exhaustion in all these cases is incomplete. I think it would be very interesting, if Mr. Howell has the facilities, to study the blue discharge by means of the spectroscope. Possibly we can thus get information as to what matter is present, giving rise to the discharge.

Secretary Pope (in the chair):—The questions involved in this very interesting paper are necessarily confined to the observations of those who are engaged in a special branch of the business, and for a moment, when Mr. Colby spoke of the date

of his notes, I paused to think whether we had incandescent lamps in 1883. I think it would be of interest, when Mr. Howell rises to close the discussion, if he would intimate what bearing this investigation has upon the manufacture of lamps, or possibly its interest to users of them. How these lamps are made, and the intricate processes they go through in treating these filaments, is of course a sealed book to many. If there are any gentlemen present who are not members of the INSTITUTE, they are at liberty to make any remarks or ask any questions of the author.

MR. DOUGLASS BURNETT:—I have a request to make of Mr. Howell, that in closing his remarks he will tell some of the younger members what tamadine is.

MR. COLBY:—Tamadine is a name which unfortunately conveys very little meaning. It is a name which was compounded by one of Mr. Weston's assistants—his secretary, I believe—who had a more familiar acquaintance with the Greek language, or more time to hunt up Greek words which would convey the true meaning of what was intended than the rest of us. Tamadine is simply a cellulose filament which is made by dissolving ordinary gun-cotton in a mixture of ether and alcohol; pouring the solution on a glass plate, the solvents evaporate, leaving what is generally known as collodion. Of course in this state it is highly inflammable, and it must be treated chemically to remove the oxygen combined with it before it can be carbonized. The advantages claimed for it were that it gave a homogeneous filament. [The literal meaning of tamadine being "without structure."] Now that I am up—I am sorry to take so much time, but these notes I have not looked over for a good many years—I find on December 26, 1883, that I made a lamp in the shape of a U tube for the purpose of investigating still further this blue discharge. It was a lamp with a large filament, 125 C. P. lamp, and a straight tube was made of sufficient length to contain this filament, and then bent up in the shape of the letter U. In this way a most effective screen was interposed between the positive and negative legs. I exhausted this lamp as finely as possible, increasing the current until both stubs were very hot, without noting the least trace of discharge. After burning at high candle power for several hours, the carbon was perfectly clean. In other words, there was no discoloration of the negative leg, as is often observed, but the sides of the tube were badly blackened. The mechanical difficulties of making a lamp of this character were too great, of course, to adapt it to commercial purposes.

MR. WOLCOTT:—In connection with the explanation of what tamadine is, I will say it is entirely new to me that tamadine is nitro-cellulose, or celluloid, as you may say. I certainly read in the electrical journals once that it was made by treating cellulose proper with ammonium sulphide. Some one wrote an article saying that that was what it was.

MR. COLBY:—It was made as I described a moment ago, in the laboratory. To turn it out in large quantities, of course that process was altogether too slow, and we resorted to the facilities of the Celluloid Manufacturing Company of Newark, and they made it by treating ordinary tissue paper and reducing it to the chemical state such that it became soluble in a mixture of ether and alcohol with certain other compounds.

MR. WOLCOTT:—They made nitro-cellulose of it.

MR. COLBY:—Practically. I cannot speak with knowledge of their process or the exact chemical composition, because that is a secret they keep themselves.

MR. WOLCOTT:—Some one wrote an article—I forget who it was—stating that Mr. Weston had discovered a process of forming this material by treating the cellulose or paper with ammonium sulphide, and that is entirely different. Of course I do not know whether there is anything in that or not.

MR. COLBY:—That is something I never heard of. The only use to which we put ammonium sulphide was to reduce the nitro-cellulose. It was treated with that to render it less inflammable. Very likely that is the origin of the statement

MR. CHARLES WIRT:—I have never seen a statement of the fact that contact resistance between metals has a negative temperature co-efficient. This is a fact which I found out by experiments some years ago, and I have always associated this peculiarity with the negative temperature co-efficient carbon, which being (at least in most forms) of rather loose structure and of high resistance, is rather suggestive of contact resistance between particles. The reversal of this temperature curve in Mr. Howell's diagram interests me very much, and I would like to know more about it. It looks as if that sample of graphite, after passing a certain temperature, became something that was not graphite. We get a striking change in the nature of phosphorus by simple heating of the material, the resulting allotropic form being decidedly unlike the original. If Mr. Kennelly or Mr. Howell, or somebody else, would investigate this graphite further, perhaps we may learn how to make diamonds.

MR. HOWELL:—Mr. Kennelly suggests that the argument which I made that the heating effect observed on the positive joint, or on a positively connected inserted wire, was not due to molecular bombardment was not conclusive. The lamp shown in Figure 10 had a copper plate an inch long and about a quarter of an inch wide between the legs of the filament, and the filament itself was only one and one-half inches high, so that the little globule which you see in Figure 10 at the end of the wire is the result of the melting of a copper plate which extended two-thirds at least of the length of the loop. In that lamp there was no indication of heat on that copper plate, unless this external wire was connected with the positive terminal. The plate would naturally receive a very large proportion of the molecular

bombardment, which was directly across, between the two legs. It shielded the positive joint of the lamp from a large part of the direct molecular bombardment, and yet it would not get hot, and the positive joint would get hot; but just as soon as that middle plate was connected to the positive wire, then that plate got hot and the joint got cold. I think that is quite conclusive that the bombardment itself does not produce very much heat. It may produce some, but not very much until there is positive connection made which allows the molecules to discharge to a point of high potential.

Mr. Kennelly also suggests that my conclusions are somewhat in conflict with those of Professor Fleming. They are not. Professor Fleming's work was all done with lamps which were highly exhausted. All the highly exhausted lamps with which I experimented behaved exactly as Prof. Fleming's did. There was every indication that the molecules passed in straight lines only. They would not pass around the screen shown in Fig. 11, and their effects would not be exhibited in the lamp shown in Fig. 12 when the negative leg was in the tube. The power to pass in other than straight lines exists only, so far as my experience shows, when the vacuum is in a condition to give a blue glow. In that case I believe that there is a large number of molecular collisions constantly occurring in the vacuous space, and perhaps the charged molecules do not go from the negative to the positive around corners, but go to other molecules to which they give up their charge. Probably the motion is in a number of straight lines instead of one. But in all cases in which the lamp had a high vacuum, as it was in all the lamps Prof. Fleming used, I found no ability to pass in other than straight lines.

Mr. Colby speaks of substituting for the galvanometer a telephone for exploring the potentials of the vacuous space. That point was very thoroughly covered by Professor Fleming, with a condenser, which is still better than a telephone. The indications of the telephone are not simply indications of potential, but are indications of current, and the current in this case must depend on the number of molecules which are received by the positively connected wire. His experiments with a telephone are entirely in accord with all of my experience, which shows the current a maximum between the positive terminal and a point near the bottom of the negative leg of the filament, and that as you go distant from the foot of the negative leg you get less and less total bombardment for given surface, and less effect on the telephone. But with the condenser you find the potential is the same everywhere; anywhere in the vacuous space in which you insert a wire and get its potential difference between the positive electrode and that point. In fact, every point of the vacuum is reduced to the potential of the negative leg. The condenser was allowed to charge, and was discharged through a ballistic galvanometer.

Mr. Colby's question as to whether the luminosity was due to the energy of carbon or of other molecules, I do not know that I can answer fully; but I think there is every indication that it is due not to carbon molecules but to others. I do not think it is possible to get a blue glow in a lamp after it has been well exhausted—after it has been exhausted of everything except the carbon molecules which come from the filament. It is only to be obtained when there is some other gas or vapor in the lamp. Water vapor causes a very marked blue effect. One fact which I mentioned in this paper was that in the presence of a blue discharge, if a direct current is used in heating the filament, a black deposit will appear on the negative leg, and yet you know that the bombardment which affects the galvanometer is from the negative leg. Yet the black appeared on the negative leg, showing that there is a transfer of carbon molecules, probably from the gas in the bulb, to the negative leg, and that is always observed where you have a blue glow, but you can never observe that in a well exhausted lamp. When a filament is heated with a direct current the carbon molecules proceed from both legs equally. I do not think there is any evidence in my possession which indicates that there is a greater throwing off of carbon molecules from one leg than from the other. I know that other observers have stated that there was such evidence, and that the carbon molecules were thrown off very freely from the negative leg. There is no evidence which I have which supports it. There is plenty of evidence that if one leg of the carbon is a little thinner than the other, and hotter, it will throw off a good deal more carbon at its higher temperature. But the great number of lamps which I have seen which show an equal shade on both sides of the bulb indicate that that is equal from both legs when both are equally hot.

Mr. Wirt's suggestion as to the investigation of graphite of high temperatures and the possibility of its changing into something which is not graphite is worthy of consideration. But the fact immediately presents itself that when the carbon is cold it is graphite again. It is pretty hard to investigate a white hot substance which has the power to go back to its old condition when it gets cool again.

Mr. Pope speaks of the bearing which this paper has on the manufacture of lamps. The only bearing it has is to tell us not to make lamps that show blue.

The action of these molecules emanating effectively from the negative leg only, is very curious, and I hoped that the suggestion which I made at the very end of this paper would be taken up and discussed by somebody who knew more about it than I did; that is, that the action of these molecules in carrying electricity in one direction only, may be an indication of the nature of the action between molecules in solid conductors, carrying conductors, rather than an illustration of the action of statically

charged molecules. I think there is evidence that the action of these molecules has very little to do with their static charge. We know that in order to produce effects by a static charge in an ordinary vacuum you have got to use very high potentials and quite a large amount of actual energy. Whereas in these cases, a lamp which requires a very low potential difference will give a very strong molecular effect, and its passage in one way only is rather hard to explain. In fact, Prof. Fleming does not explain it. He says it is so because it is so, practically, and I am sure I cannot explain it. But it is a fact that the current is carried in one direction through the vacuum just as it would be if it were a conductor with all its resistance at the positive contact. If this were so, an inserted wire would show the same effects as those we observe in actual lamps. We have measured currents as high as 25 amperes passing through a space in which there is no continuous matter—that is, matter in the continuous condition we think of when we speak of a solid. When that current is passing, there is a vacuum there which is so high that it would scarcely depress a barometric column. In fact, I tried to measure whether there was a depression of a mercury column, and if there is any it is very slight indeed. Under proper conditions, a vacuum which will not appreciably depress a mercury column will carry a current and appear to have practically no resistance except at the positive contact. The vacuum will sometimes change from an insulator to an almost perfect conductor suddenly, without any gradations at all. It will be a sudden change due only to a suddenly acquired ability of the molecules to carry the current across the space in one direction only. The indication of the unidirectional current from the alternating current is very interesting. It was a natural result, and it was one which I predicted before I tried it. I made an indicator for an alternating circuit in that way by using a lamp with a third wire which had a high degree of exhaustion on an alternating circuit, the alternating circuit giving the carbon its temperature, and the variations in the current affected an ordinary direct current galvanometer connected between the inserted wire and one electrode, and it seemed very strange to see an undirectional current taken out of an alternating current in this way.

On motion of Mr. Kennelly a vote of thanks was tendered to Mr. Howell for his very interesting paper.

[Adjourned.]

[Communicated After Adjournment by Prof. W. M. Stine.]

Prof. W. M. Stine:—Perhaps the most elaborate investigations of the "Edison effect" have been carried out by Professor J. A. Fleming. In a lecture before the Royal Institution, in 1890,[1] he developed about all the leading facts which he has since elaborated.[2] His experiments, together with those detailed in the paper under discussion, reveal a large number of facts, interesting alike to the student of physics and the manufacturer and user of the incandescent lamp.

In Professor Anthony's paper before the Institute in 1894, it was stated that carbon was removed from the filament through the action of convection currents. This was taken exception to at the time, and the evidence from experiments on the "Edison Effect" clearly disprove this assumption. In one of the lamps employed by Professor Fleming, containing a sealed-in aluminium plate, this accidentally vaporized, coating the walls with metallic aluminium, and leaving a well-defined molecular shadow of the filament. It may then be held that in the high vacuum of an incandescent lamp, metals or carbon brought to incandescence truly vaporize, and the molecules leave the surface and travel in straight lines, having a fairly free molecular path. Nor can the driving off of carbon molecules from the filament be regarded as an electrical act; it is rather due to evaporation at high temperature, and can be assisted by electrical repulsion but to a limited extent, since the voltage in lamp filaments is usually very low. This is confirmed by the present paper. Mr. Howell found the "Edison Effect" to be as strong between the filament legs of a 40-volt lamp as one operated at 140 volts, it being assumed that the temperature of incandescence was the same in each case. In a curve given by Professor Fleming, the "Edison Effect" is approximately a linear function of the volts between the lamp terminals. The temperature of the filaments in such a case is itself almost a linear function of the volts. His curve actually bends slightly downwards,[3] showing the influence of increased heat losses by radiation. Had the evaporation been influenced by the highest voltage to any appreciable extent, the curve must have bent *upwards*. Again, were the discharge of the molecules due to their static charges, the "Edison effect" would occur in a filament of uniform cross-section about equally over the entire surface. Another noteworthy experiment of Fleming was to seal similar filaments in the end of an egg-shaped tube. These were heated to incandescence by battery currents. A single cell of battery connected to points on the two filaments, which were at equal potentials, was able to send a marked current through the tube. This experiment establishes

1. Reprinted in *Scientific American Supplement*, August 23, 1890.
2. *Phil. Mag.*, July, 1896.
3. *Phil. Mag.*, July, 1896, p 57.

two facts: that incandescent carbon fills a vacuum tube with a carbon atmosphere of high conducting power, and that this vapor conducts an electrical current much as does a solid conductor.

Perhaps the most singular phenomenon in this connection is the unilateral nature of electrical discharge from an incandescent source. The carbon vapor itself conducts equally well in any direction, but the discharge takes place only from the negative side of the filament. This, again, is another proof that the "Edison Effect" is not a static one, since the entire filament would be covered with a static discharge of the same sign. Guthrie long since showed that an incandescent conductor would discharge negative but not positive electricity. The action of the Crookes tube with cold electrodes is, in the main, of a similar nature. These facts indicate, as Lord Kelvin pointed out some years since, that there is a radical difference in character between positive and negative charges. It is probable that we shall yet find in such facts as these the explanation of the nature of electrical conduction.

A very significant statement is made on page 39 of the present paper, in connection with the sudden appearance of the blue glow in the lamp. The same thing is frequently seen in Röntgen tubes. With a very high vacuum scarcely any current passes. If the tube is heated, the vacuum is lowered gradually until a critical point is reached. At this point a blue glow suddenly appears about the anode, and the resistance of the tube very materially decreases, with an equal suddenness. At this point the atmosphere seems to cease carrying the current by moving electrical charges, and becomes, in a sense, a true conductor.

Another interesting effect is, the larger the conducting plate sealed into the bulb, the greater the flow of current. The subject is one of great practical importance. It clearly points out the value of high exhaustion for lamps. That a lamp containing an atmosphere of a heavy, non-conducting gas, such as bromine, exhibits these effects but feebly, is also significant. High efficiency lamps, even with excellent vacuum, ought not to be pushed to a high filament temperature, or they become to a certain extent short-circuited. This indicates an unfortunate limit to the increase of the efficiency of carbon filaments. It is probable that though the "Edison Effect" may be decreased, it can never be wholly avoided, since a carbon burned in the air will exhibit the effect while it lasts. Lamps containing heavy non-conducting gases in their bulbs, as Professor Anthony has shown, do not blacken to any extent. The present paper shows how small the "Edison Effect" is in them.

OBITUARY.

Ezra Carl Breithaupt (Associate Member June 6th, 1893; Member, May 19th, 1896), fourth son of the late Louis Breithaupt, was born in Berlin, Ontario, on February 19th, 1866, and there he received his early education. He attended the Northwestern College, at Naperville, Ill., and graduated from it in 1887. He travelled for some time, and then went to Johns Hopkins University, at Baltimore, to take the course in electricity. In 1892 he graduated from Johns Hopkins with the degree of "Electrical Engineer," and, on returning to Berlin, he became the Manager of the Berlin Gas and Electric Company, which position he held up to the time of his death.

As consulting and electrical engineer, he had a general practice in Ontario and Quebec, and as such he acted for the town of Bracebridge on the installation of a large lighting plant. He laid out and superintended the work of electrically equipping the Berlin and Waterloo Street Railway, and later became its president and manager. He also acted as consulting engineer for the town of Sherbrooke, Quebec, for the Penetanguishene and Midland Electrical Railway Company, and for various other enterprises.

He was a member of the Canadian Electrical Association since its inception, and was a most active and valuable member of its executive and statistics committees, of which latter he was chairman. In June last he was elected to the office of second vice-president of the association. During his connection with the association he prepared and presented to it several valuable papers, and he also contributed papers to various electrical publications, principally dealing with Canadian developments in electrical engineering.

He was a member of the Berlin Board of Trade and of the Toronto Board of Trade, and at one time was president of the former.

Mr. Breithaupt's death, on January 27th, 1897, resulting from injuries received at an explosion of an oil tank at the Berlin gas works, is particularly sad, as it came at what was only the beginning of a career of great promise. He leaves a large circle of relatives and friends to whom his affability, his manliness and his conscientiousness had endeared him.

REPORT OF COMMITTEE ON UNITS AND STANDARDS.

To the President and Council of the American Institute of Electrical Engineers.

Gentlemen :—

Your Committee on Units and Standards having carefully considered the communications which you have referred to us, recommend :—

1st. That Hefner-Alteneck Amyl-Acetate Lamps furnished with test certificates from the Physikalisch-Technische Reichsanstalt at Charlottenburg, Berlin, should be temporarily adopted as concrete standards of luminous intensity, or candle power.

2nd. That in measuring the mean horizontal luminous intensity or candle power of an incandescent lamp, a Lummer-Brodhun photometer screen be adopted, and that the incandescent lamp be steadily rotated about a vertical axis through its axis of figure at a uniform speed of approximately two revolutions per second.

Your Committee believe that the adoption of these recommendations would lead in practice to a much greater degree of uniformity in results of measurements of the candle power of incandescent lamps, by different and remote observers than is now usually attainable.

Although incandescent lamps are at present rated by their horizontal candle power, yet, since the only true criterion of the total quantity of light emitted by a lamp is its mean spherical candle-power, we recommend that the rating of lamps should be based upon their mean spherical candle-power so far as is commercially practicable.

Yours respectfully,

A. E. KENNELLY, Chairman.
F. B. CROCKER,
W. E. GEYER,
G. A. HAMILTON,
W. D. WEAVER.

January 19th, 1897.

DATE OF GENERAL MEETING.

The Council has decided to hold the General Meeting of the INSTITUTE at Greenacre-on-the-Piscataqua, Eliot, Maine, beginning on July 26th. This place was the residence of the late Moses G. Farmer, who was one of the charter members of the INSTITUTE and, made an Honorary Member October 21st, 1890. He died at Chicago, May 25th, 1893, having been actively engaged in the preparation of his personal exhibit for the World's Fair. The date selected will be the 50th anniversary of Prof. Farmer's relinquishment of teaching and the taking up of electrical work. Greenacre is delightfully situated on the east bank of the Piscataqua river, about 10 miles beyond Portsmouth, N. H., and is reached in two hours from Boston. Members who may desire to present papers at this meeting are requested to communicate with Mr. Herbert Laws Webb, Chairman, Committee on Papers and Meetings, 18 Cortlandt Street, New York City, or with the Secretary.

DATE OF ANNUAL MEETING.

The Annual Meeting for the election of officers, presentation of yearly reports, etc., will be held at 12 West 31st Street, on Tuesday, May 18th, which is the third Tuesday in the month, as provided by the Constitution.

COUNCIL NOMINEES.

From the nomination returns received from the membership the Council has selected the following names which will be printed on the ballots for the guidance of members in their choice of candidates.

For President:
FRANCIS B. CROCKER, of New York City.

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HERBERT LAWS WEBB, of New York City.

For Treasurer:
GEORGE A. HAMILTON, of New York City.

For Secretary:
RALPH W. POPE, of New York City.

The officers whose terms have not expired are:—VICE-PRESIDENTS—Chas. P. Steinmetz, of Schenectady, N. Y.; Harris J Ryan, of Ithaca, N. Y.; Wilbur M. Stine, of Chicago, Ill. MANAGERS—Chas. F. Scott, of Pittsburg; Bion J. Arnold, of Chicago; Carl Hering, of Philadelphia; Cary T. Hutchinson, John W. Lieb, Jr., and F. A. Pickernell, of New York City; Wm. L. Puffer, of Boston, and L. B. Stillwell, of Niagara Falls.

NOTICE.

Written discussions of the topic contained in this issue if acceptable, will be printed in the March number, also the annual volume, if received before April 15th.

The Secretary will esteem it a favor if his attention is called to any errors, in order that they may be corrected before printing the sheets for the annual volume.

The Institute as a body is not responsible either for the statements made or for the opinions expressed, in the TRANSACTIONS.

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After printing the monthly, the papers and discussions are revised, repaged, and the sheets for the annual volume printed from the corrected type, and laid aside till the close of the year. As the index is made for the volume and not for the monthly parts, the complete volume sent at the end of the year becomes the permanent record. Upon its receipt the monthly parts are superfluous. They may be returned to this office at our expense, as there is a continual demand for separate copies of papers.

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RALPH W. POPE, Secretary,
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